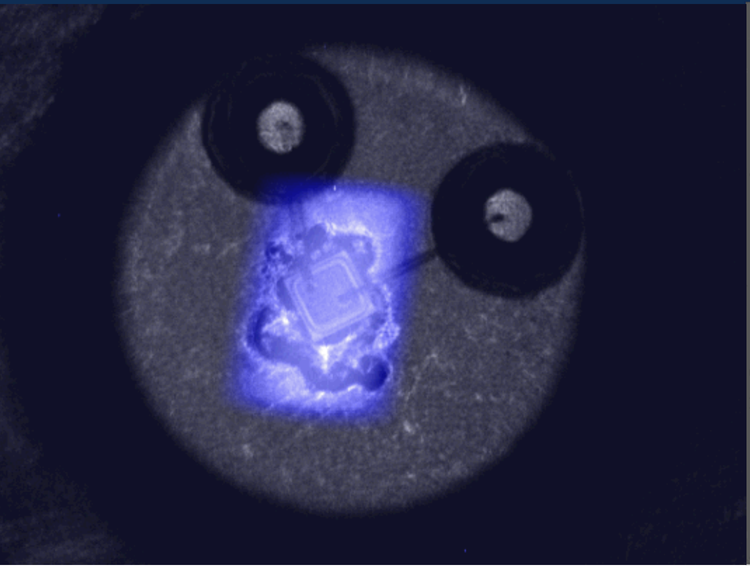

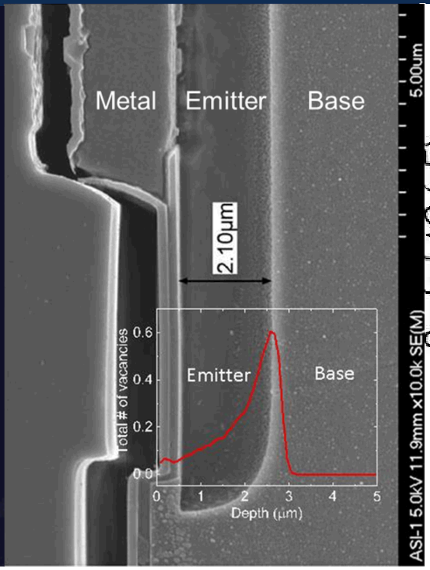


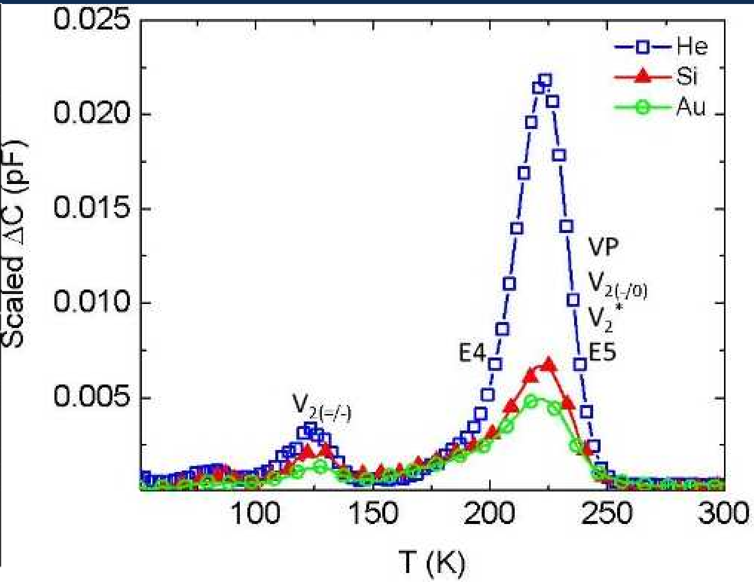


# Exploring the Effect of Defect Clustering using Deep Level Transient Spectroscopy on Silicon Transistors

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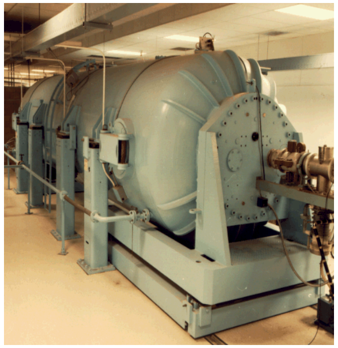
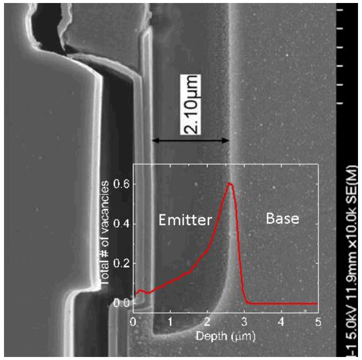
Sandia National Laboratories, Albuquerque, NM USA

IBMM 2016 October 31st 2016, Wellington, New Zealand

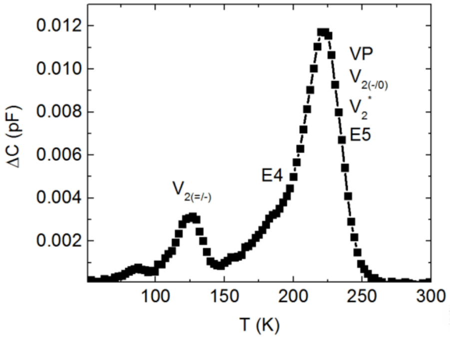
# Outline



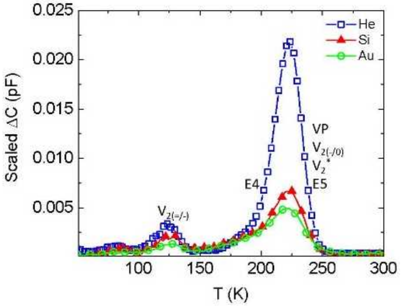
- Introduction




- Ion irradiations (End-Of-Range conditions)




- Defects characterization (DLTS)



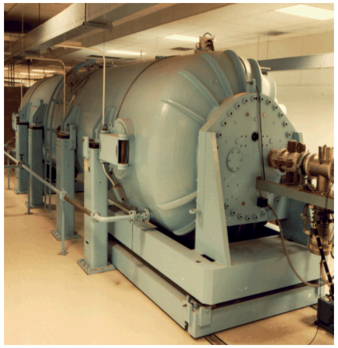

- Effect of ion species on defects

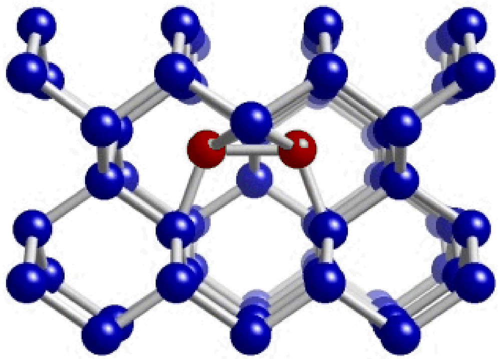
- Conclusions

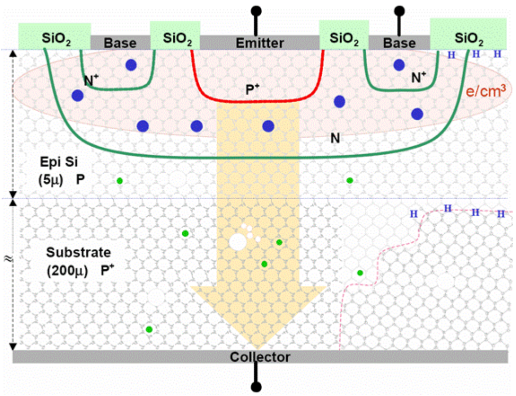
# Defect Study Motivation – Displacement Damage

## Radiation Effects

6.5 MV Tandem Accelerator



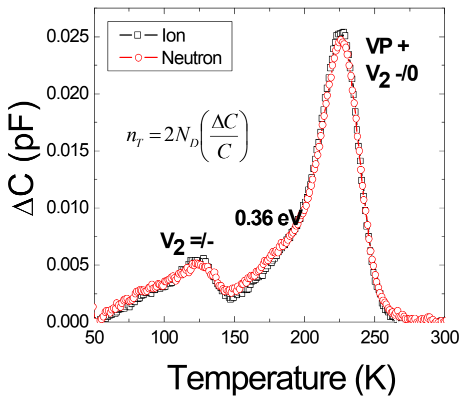




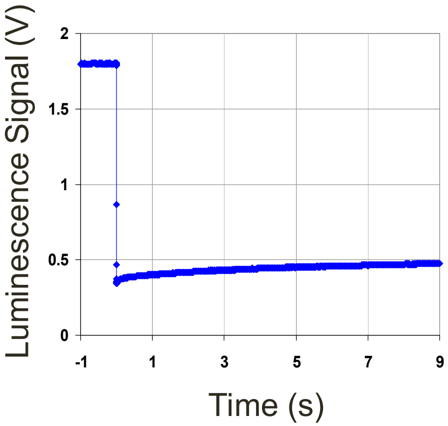

## Experimental Techniques at the Ion Beam Laboratory (IBL)

We use a series of techniques to explore the defect creation and annealing on Si BJTs

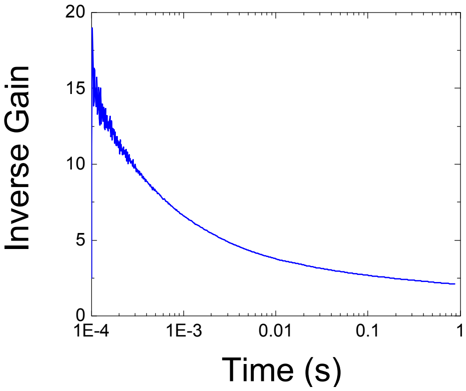
Deep-level Transient Spectroscopy (DLTS)




Photoluminescence



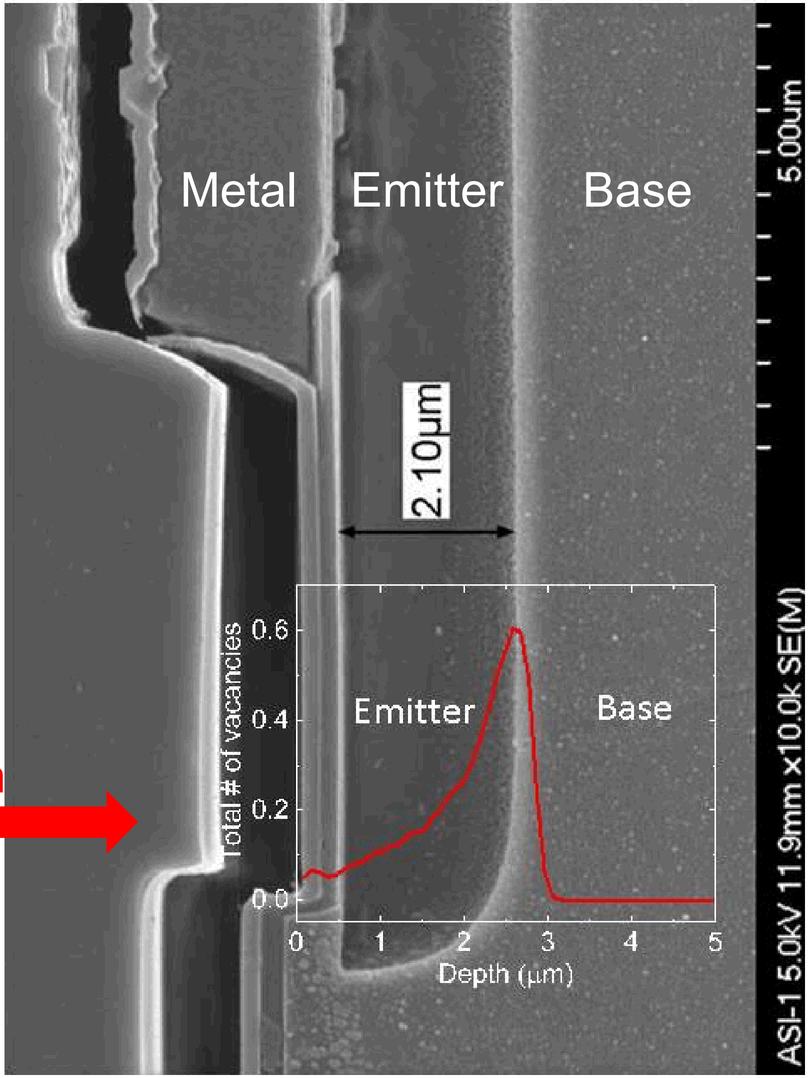

Active Gain



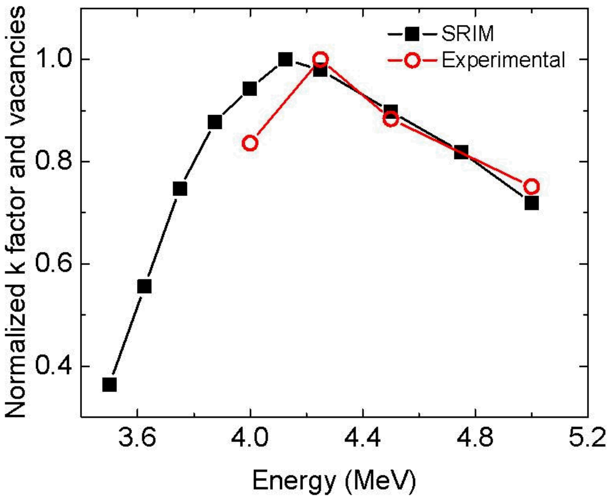

Use late time DLTS to explore the type/number of defects created by different mass particles

# End-of-Range (EOR) Ion Irradiations

Ion beam




- Device: Microsemi 2N2907 pnp BJT
- Target base-emitter (BE) junction




- EOR conditions for different ion species:

He: 850 keV

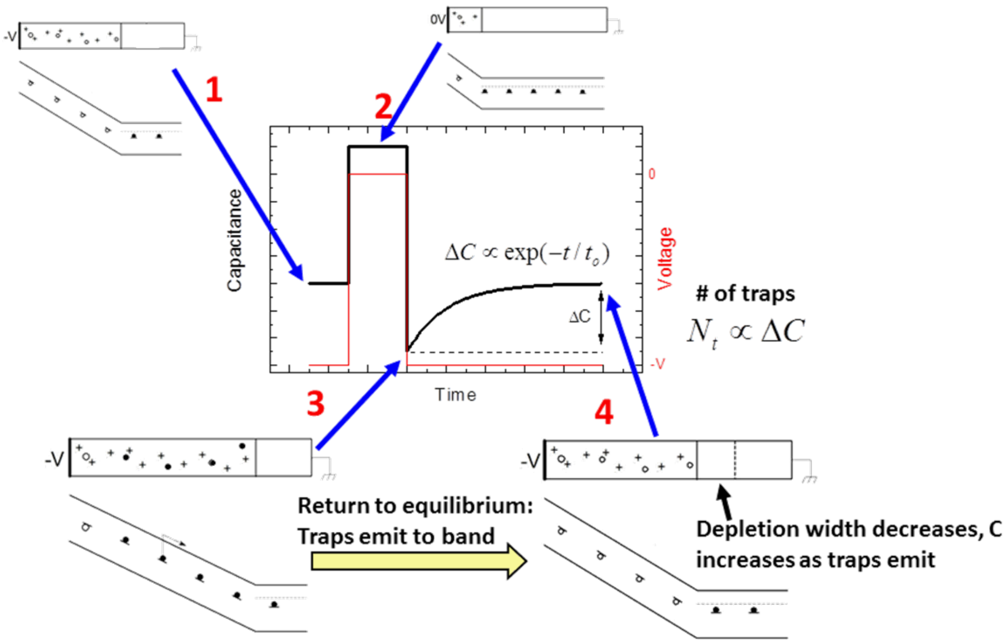
O: 3.75 MeV

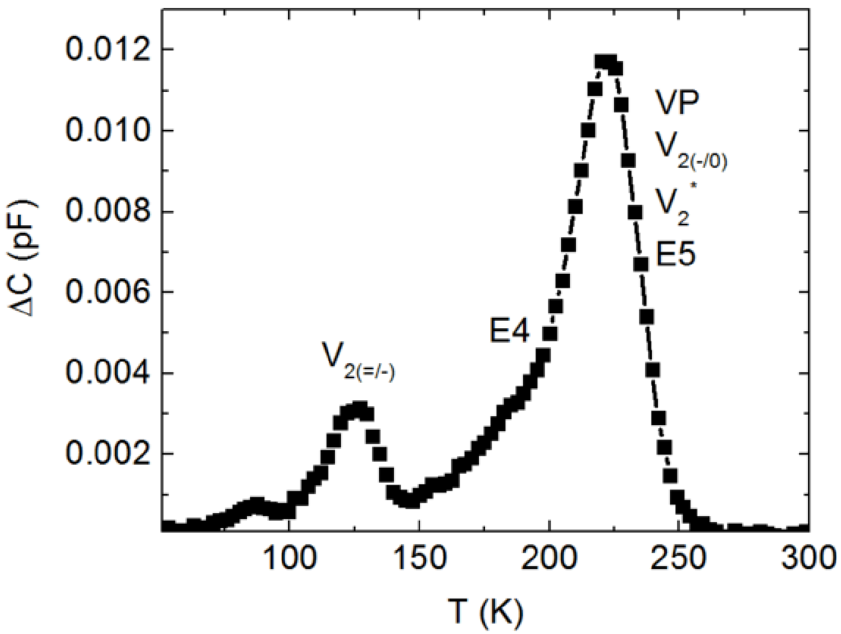
Si: 4.25 MeV

Au: 11 MeV

Use end-of-range ion irradiations to target the BE junction → maximum damage

# Deep Level Transient Spectroscopy (DLTS)

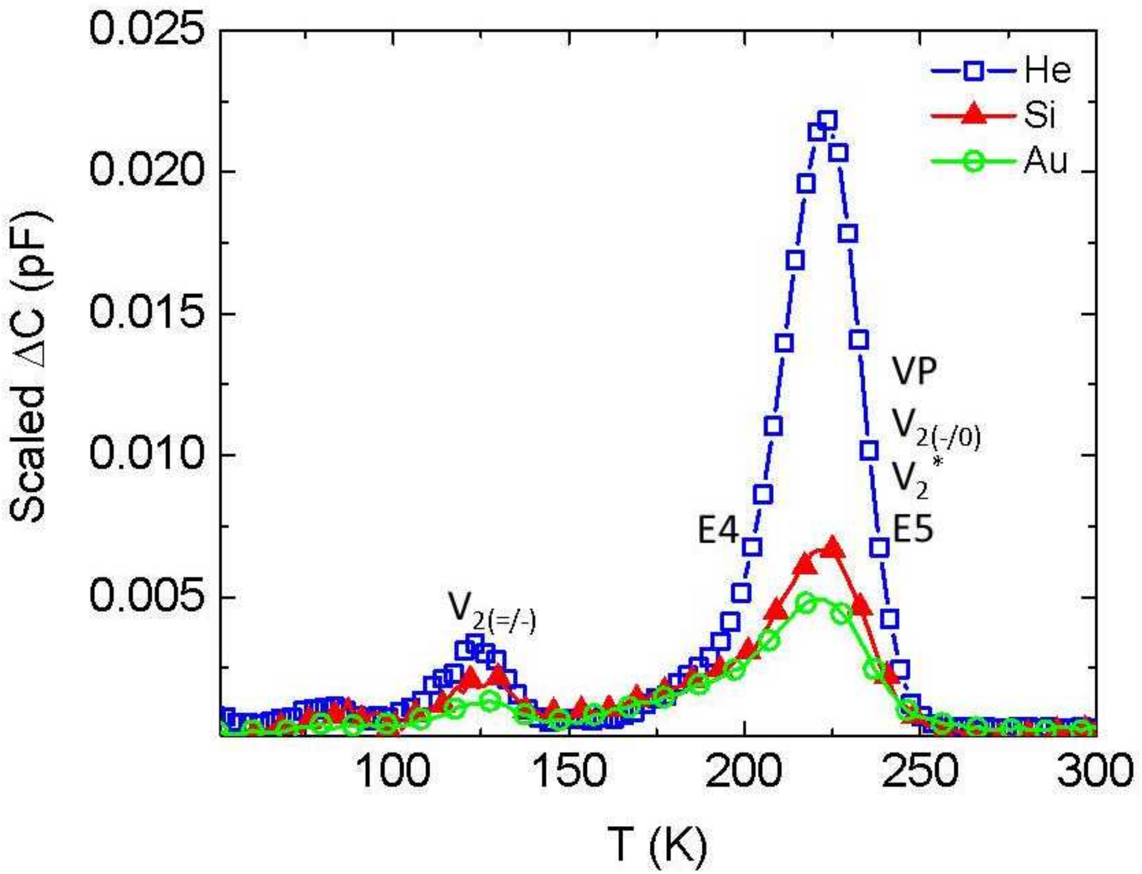



- $V_{2(=/-)} = V_{2(-/0)}$ → Same divacancy defect with different charge state
- E4 = E5 → Same divacancy-like defect with different charge state
- VP = Vacancy-Phosphorous defect
- $V_2^*$ = Strain divacancy defect

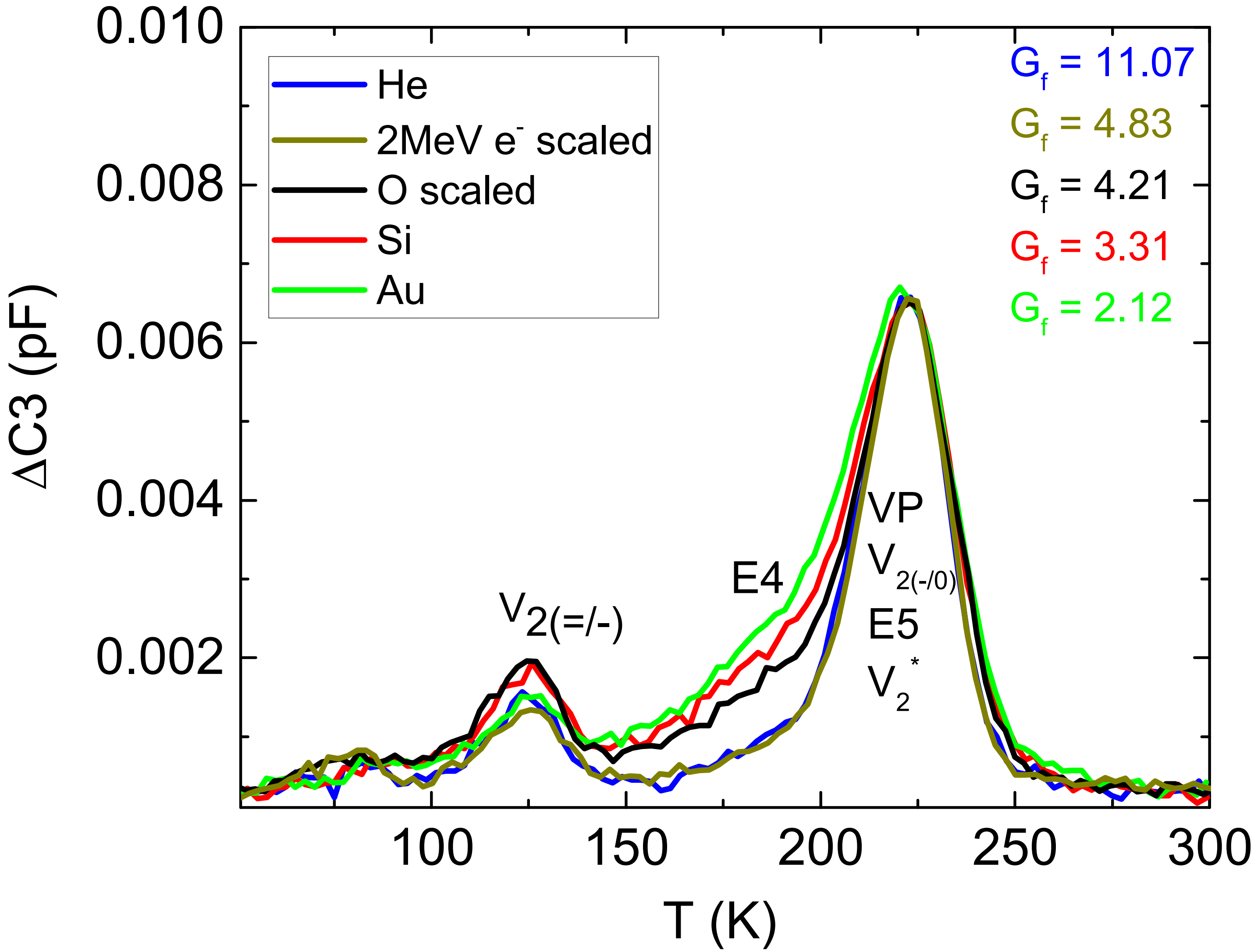
Type and number of electrically active traps can be know using DLTS

# Matched gain conditions ($e^-$, He, O, Si & Au)




If we match gain, we see a big difference in amount of defects produced by different ions

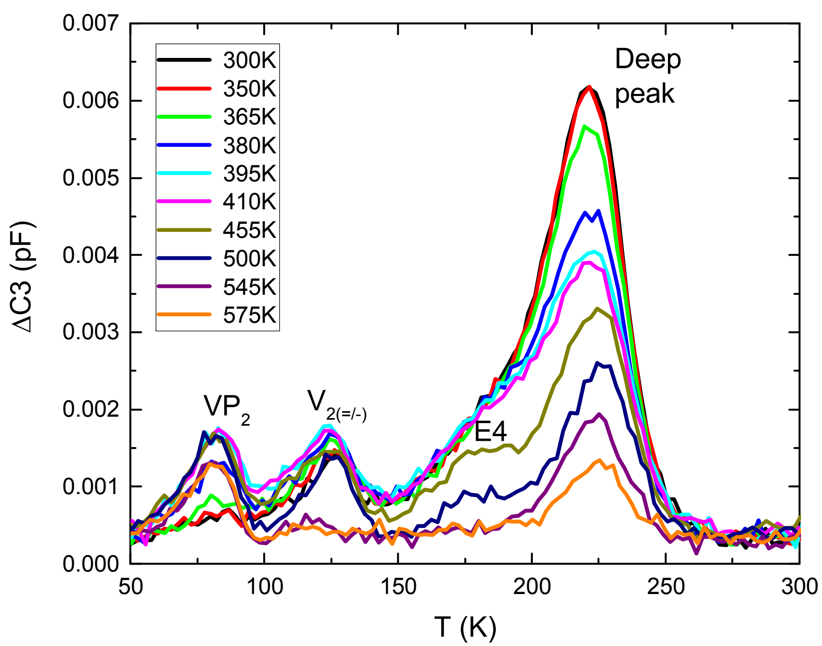
# Matched defect conditions ($e^-$, He, O, Si & Au)



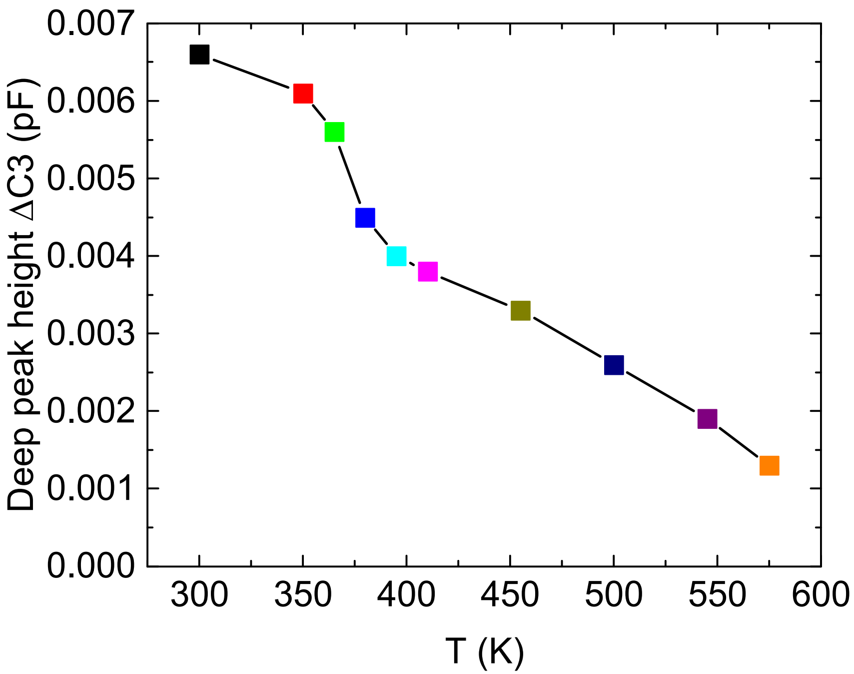

Amount of E4 produced by clustering varies with ion mass

# Isochronal anneals → 350K, DLTS, 365K, DLTS, 380K, DLTS…

- DLTS spectra for different annealing temperatures



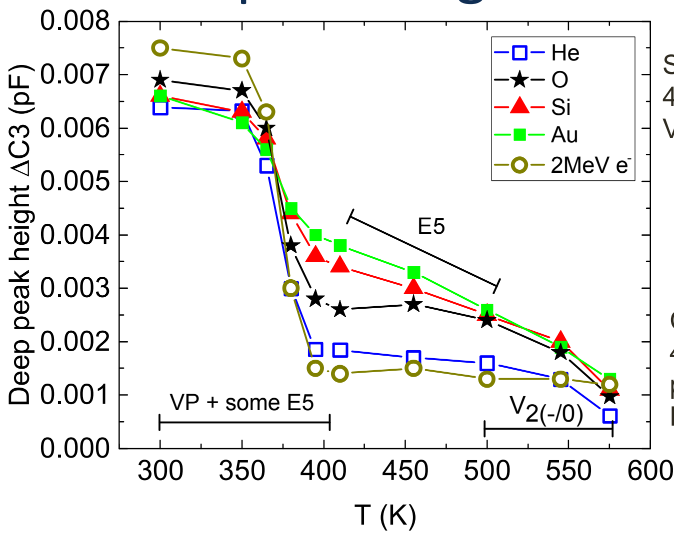

- Deep peak height vs. annealing temperature




Deep peak = VP + E5 + $V_{2(-/0)}$ + $V_2^*$

Use isochronal anneals to separate defect contributions in deep peak

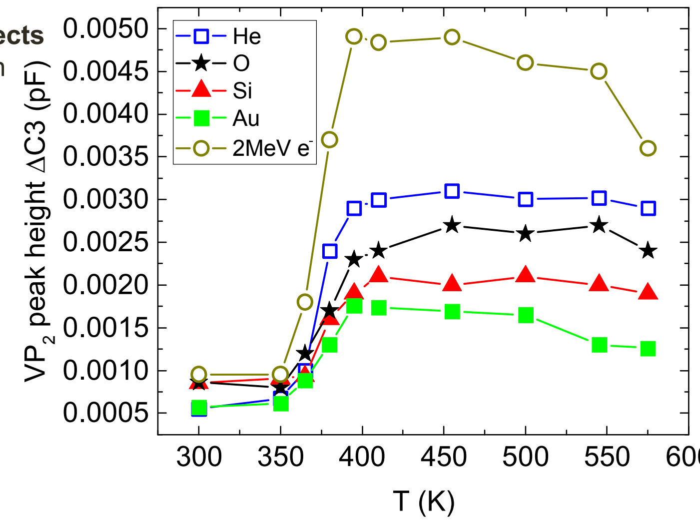
# DLTS peak heights vs. annealing temperature

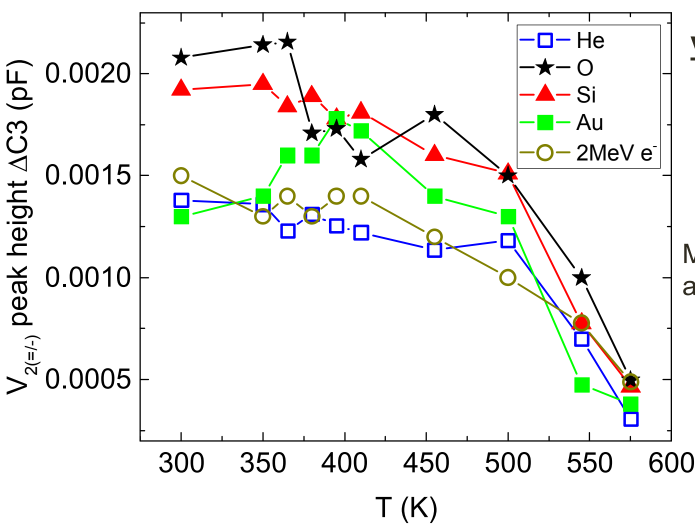



Steep drop at 410K indicates VP annealing

Constant height at 400-500K for light particles suggest no E5

More **VP defects** produced with light ion than heavy ions



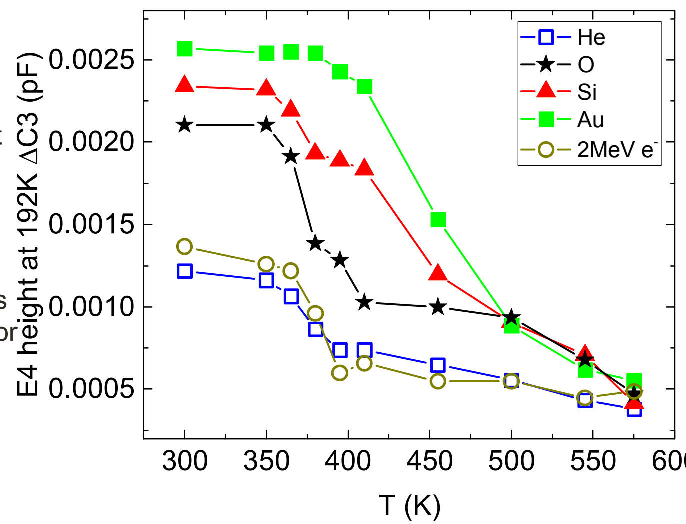




**$V_{2(-/0)}$ known** from $V_{2(=/-)}$

Majority of $V_{2(=/-)}$ anneals after 500 K

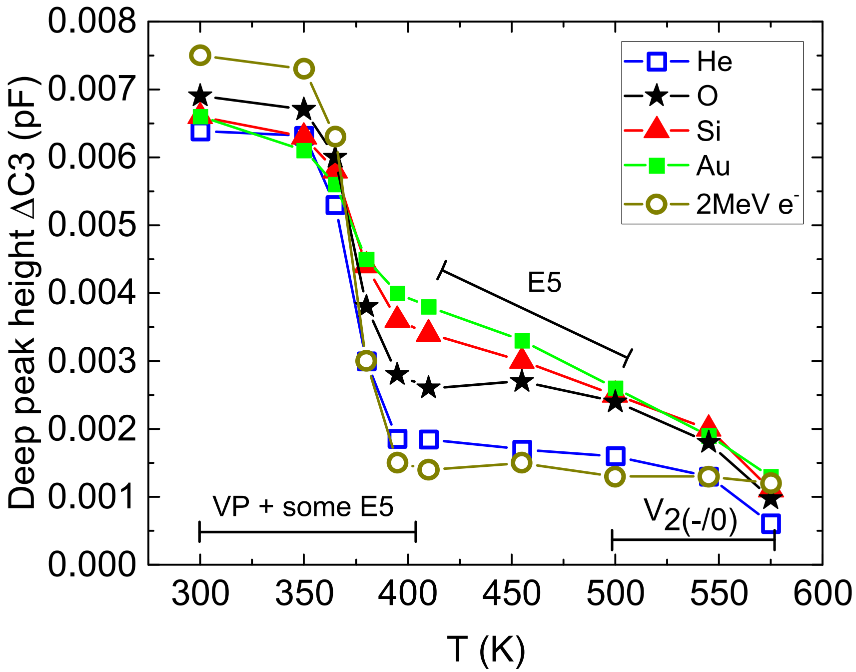
**E5 known** since E4 is same defect with different charge state

Large amounts of E4 anneal for Au vs small amounts for light ions

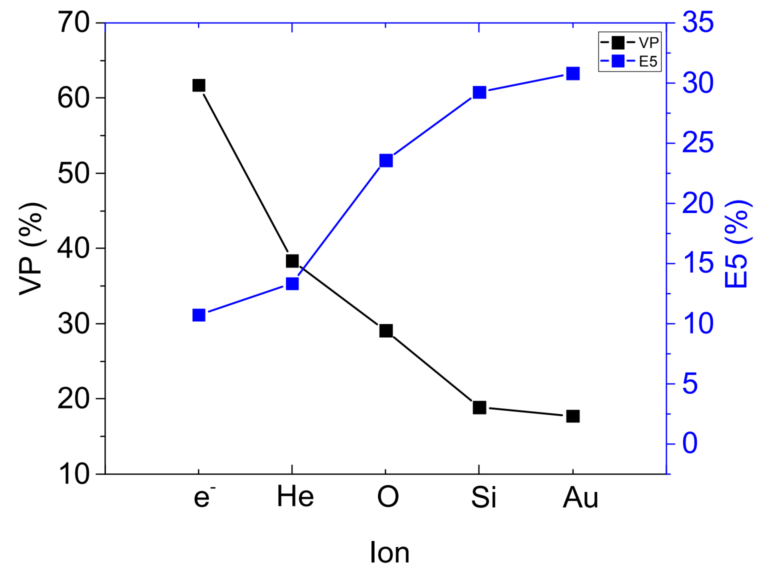



Isochronal anneals used to determine defect composition in deep peak produced by different mass particles

# Annealing experiments - Matched vacancy conditions




| | Percentages of defects in deep peak | | | | |
|---|---|---|---|---|---|
| **Defect** | **e-** | **He** | **O** | **Si** | **Au** |
| **VP** | 61.71 | 38.37 | 29.06 | 18.85 | 17.73 |
| **E5** | 10.72 | 13.34 | 23.58 | 29.23 | 30.80 |
| **$V_{2(-/0)}$** | 15.26 | 15.54 | 15.26 | 15.03 | 15.03 |
| **$V_2^*$** | 12.31 | 32.75 | 32.09 | 36.89 | 36.44 |

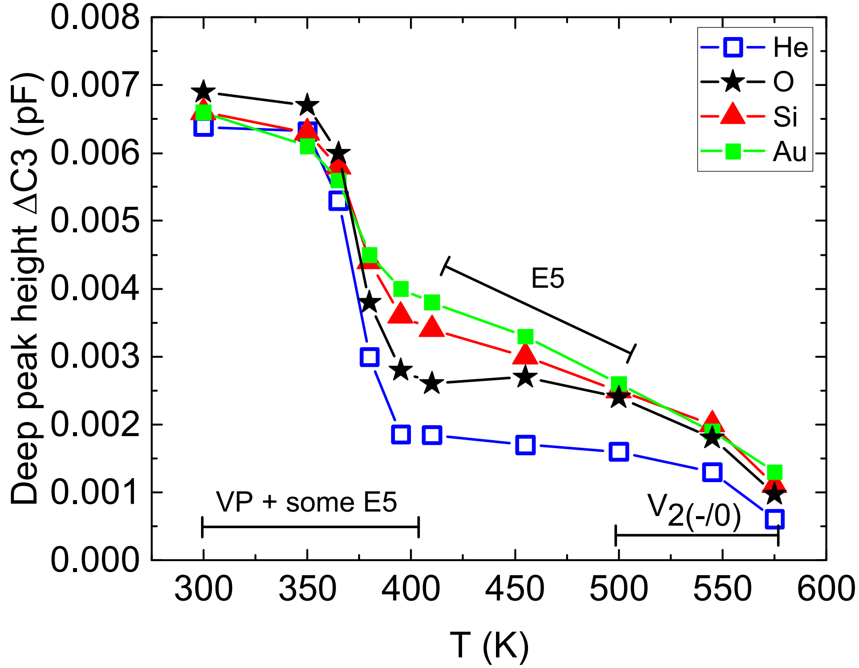


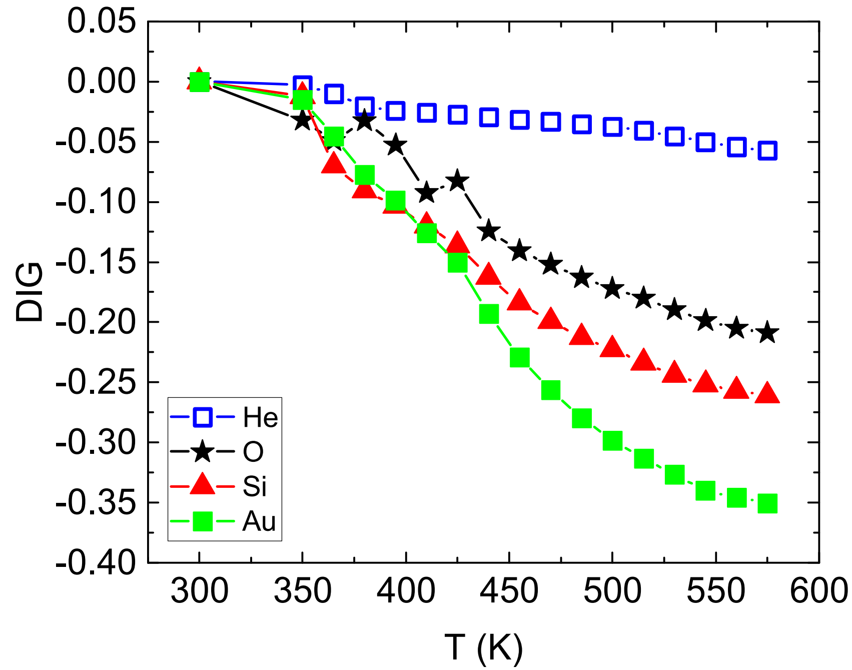

## Assumptions:

- $VP = VP_2$ (assumption: All VP convert into $VP_2$)
- E5 = E4 (Same defect but different charge state)
- $V_{2(=/-)} = V_{2(-/0)}$ (Same defect but different charge state)
- $V_2^* =$ (Deep peak) – (VP + E5 + $V_2$)

Clustering is responsible for low VP because there are less single vacancies available to form VP

# Annealing experiments - Matched vacancy conditions




$$DIG = \frac{1}{G_\infty} - \frac{1}{G_0} \propto \#\ of\ traps$$

This number grows with annealing temperature

This number stays constant with annealing temperature

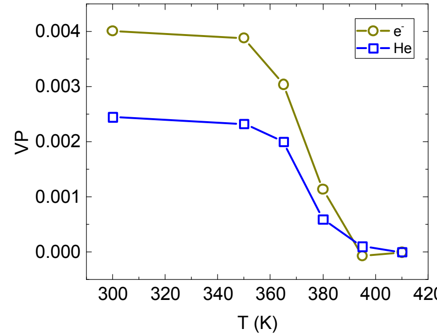
$G_\infty$ = Recovered gain after annealing

$G_0$ = Gain after irradiation

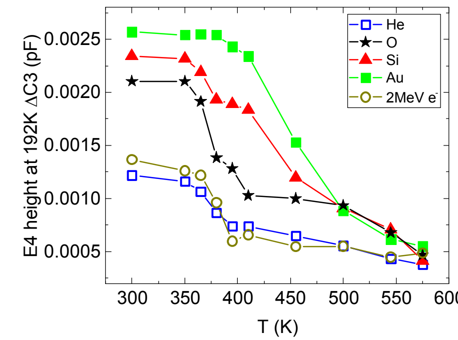
Clustering defects such as E5 and $V_2^*$ are responsible for gain degradation, not VP

# Conclusions

- Light ions produce more VP defects than heavy ions




- Heavy ions produce more clustered-related defects than light ions




- Clustering defects such as E5 and $V_2^*$ are responsible for gain degradation, not VP